AD 730775

AD

TECHNICAL REPORT
71-47-CE

EXPERIMENTAL ORGANIC FIBER MATERIALS FOR PERSONNEL ARMOR

by

Marvin R. Lilyquist

Monsanto Research Corporation

Durham, North Carolina

Contract No. DAAG17-69-C-0079

January 1971

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing & Personal Life Support Equipment Laboratory

TS-177

44

Approved for public release; distribution unlimited.

Citation of trade names in this report does not constitute an official indorsement or approval of the use of such items.

Destroy this report when no longer needed. Do not return it to the originator.

ABSTRACT (Cont'd)

from Type II and III X-500 staple fiber by the needle loom method, and ballistic fiber-resin laminate panels by the vacuum bag-autoclave forming technique. Initially, ten laminated panels were prepared for exploratory evaluation of fiber type, resin type, fabric finish and fabric loading. Twenty-five ballistic laminates were then prepared using Type III X-500 fabric and a selected unsaturated polyester-monomer resin formulation. Variables included in this group of panels were fabric loading, areal density, resin-monomer ratio and panel size.

Results showed that of the three types of X-500 fabric only Type III had sufficient ductility to be considered for further investigation.

Unclassified

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Monsanto Research Corporation Durham, North Carolina	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Experimental Organic Fiber Materials for Personnel Armor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Marvin R. Lilyquist

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1971	36	17

8a. CONTRACT OR GRANT NO. DAAG17-69-C-0079	9a. ORIGINATOR'S REPORT NUMBER(S) 71-47-CE (TS-177)
b. PROJECT NO. 1J662708DJ40	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Natick Laboratories Natick, Mass. 01760

13. ABSTRACT

A new high performance organic fiber having an unusually broad range of possible fiber physical properties, designated as X-500, was studied in various constructions for ballistic performance as a possible material for improving personnel body armor. Tensile properties of this fiber span a wide range of values from those similar to nylon and polyester to those similar to fiberglass. The modulus, however, is higher than that for nylon or polyester fibers. Three types of this fiber were spun having single filament properties spanning the achievable range of the X-500 fiber system.

Type I: T/E/Mi = 16/3.2/700
Type II: T/E/Mi = 11/8/430
Type III: T/E/Mi = 8/23/225

T Breaking tenacity in grams per denier
E Elongation at the breaking point in percent
Mi Initial modulus in grams per denier

Work was divided into four distinct phases of evaluation: fiber yarn; ballistic fabric; ballistic felts; and ballistic fabric-resin laminates. In each phase, samples were tested using existing ballistic materials specifications as guidelines. Twenty-five square yards of X-500 fabric for each of the three types were woven on a conventional textile loom. Ballistic felt samples (five yards square each) were prepared (Cont'd on attached sheet)

DD FORM 1473, 1 NOV 65 — REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tests	8					
Ballistic properties	8,9					
X-500 Fiber	9					
Body Armor	4					
Evaluation	8					
Yarns	9					
Fabrics	9					
Fabric laminates	9					
Felts	9					

Unclassified
Security Classification

Approved for public release;
distribution unlimited.

AD________

TECHNICAL REPORT

71-47-CE

EXPERIMENTAL ORGANIC FIBER MATERIALS FOR PERSONNEL ARMOR

by

Marvin R. Lilyquist
Monsanto Research Corporation
Durham, North Carolina

Contract No. DAAG17-69-C-0079

Project Reference:
1J662708DJ40

Series: TS-177

January 1971

Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

FOREWORD

This program was jointly sponsored by the U.S. Army Natick Laboratories and the U.S. Marine Corps under contract No. DAAG17-69-C-0079 to investigate a group of new, high modulus fibers developed by the Monsanto Research Corporation, Durham, North Carolina. Polyamide type yarns have proved to be the best candidates for high impact resistance in fabric or felt form. This is especially true in the matter of ballistic resistance. On the other hand, in plastic laminate form, glass fibers in woven fabric or roving form have proved to be the most effective candidate for ballistic protection either alone or as a back-up material. The Monsanto X-500 fibers, which are the subject of the present work, provide a convenient bridge between the high modulus and high strength of glass and the toughness of polyamide fibers.

The project officer for this investigation conducted under project reference number 1J662708DJ40 was Dr. Malcolm C. Henry, and the alternate project officer Dr. Roy C. Laible, both of the U.S. Army Natick Laboratories. These investigators and others involved with this report are indebted to Mr. W. J. Ferguson, U.S. Naval Research Laboratory, Washington, D.C. for his considerable technical assistance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A new high performance organic fiber having an unusually broad range of possible fiber physical properties, designated as X-500, was studied in various constructions for ballistic performance as a possible material for improving personnel body armor. Tensile properties of this fiber span a wide range of values from those similar to nylon and polyester to those similar to fiberglass. The modulus, however, is higher than that for nylon or polyester fibers. Three types of this fiber were spun having single filament properties spanning the achievable range of the X-500 fiber system:

Type I: T/E/Mi = 16/3.2/700
Type II: T/E/Mi = 11/8/430
Type III: T/E/Mi = 8/23/225

T Breaking tenacity in grams per denier
E Elongation at the breaking point in percent
Mi Initial modulus in grams per denier

Work was divided into four distinct phases of evaluation: fiber yarn; ballistic fabric; ballistic felts; and ballistic fabric-resin laminates. In each phase, samples were tested using existing ballistic materials specifications as guidelines. Twenty-five square yards of X-500 fabric for each of the three types were woven on a conventional textile loom. Ballistic felt samples (five yards square each) were prepared from Type II and III X-500 staple fiber by the needle loom method, and ballistic fiber-resin laminate panels by the vacuum bag-autoclave forming technique. Initially, ten laminated panels were prepared for exploratory evaluation of fiber type, resin type, fabric finish and fabric loading. Twenty-five ballistic laminates were then prepared using Type III X-500 fabric and a selected unsaturated polyester-monomer resin formulation. Variables included in this group of panels were fabric loading, areal density, resin-monomer ratio and panel size.

Results showed that of the three types of X-500 fabric only Type III had sufficient ductility to be considered for further investigation.

EXPERIMENTAL ORGANIC FIBER MATERIALS FOR PERSONNEL ARMOR

I. INTRODUCTION

The present materials of choice for personnel body armor are fiberglass for reinforced plastics and nylon or polyester for ballistic cloths or felts. Glass is brittle, requires special handling, and shows sensitivity to high moisture environments unless carefully protected. Nylon and polyester show moderate strengths and good transverse critical velocities.

A new synthetic fiber designated by the code name X-500, prepared from a unique aromatic polymer system, possessed a balance of properties unusual to synthetic organic fibers. On the other hand, a nylon-like fiber having significantly higher modulus values could be achieved. Thus, X-500 with its high strength, high modulus, lack of moisture sensitivity and good handling qualities was considered to be an excellent candidate to achieve improvements in protective capability and reduction in weight. At the same time, it might provide a general purpose material for protective applications, thereby reducing the number of different fibers needed for the variety of protective applications.

This study covered preparation and supply of samples for four distinct phases of X-500 ballistic evaluation: fiber yarn; fabric; non-woven felts; and reinforced laminated composite structure. Three types of this fiber were spun having single filament properties spanning the achievable range of the X-500 system. They are: Type I: T/E/Mi = 16/3.2/700; Type II: T/E/Mi = 11/8/430; and Type III: T/E/Mi = 8/23/225

T Breaking tenacity in grams per denier
E Elongation at the breaking point in percent
Mi Initial modulus in grams per denier

It was intended both to correlate basic fiber properties with end use and to provide end use items to evaluate performance in personnel protection. Samples of X-500 yarns were made having different tensile properties (Phase I); woven fabrics prepared from the various yarn samples (Phase II); non-woven felts prepared from the various yarn samples (Phase III); and fabric reinforced laminated panels prepared from the various fabric samples and commercially available resins (Phase IV).

II. EXPERIMENTAL PROCEDURES AND DISCUSSION OF RESULTS

A. Phase I - X-500 Yarn

The objective of this phase of the work was to prepare one-pound yarn samples of new experimental high modulus fiber, X-500, having the following single filament properties when tested on an Instron tester at standard conditions of 65% RH and 70°F at 1-inch gauge length and 100% extension per minute. These values can be compared with similar values obtained for the current ballistic fibers, nylon and "E" glass.

	X-500 Fiber Properties			Current Ballistic Fibers	
Property Designation	High Tenacity High Modulus Low Elongation	Intermediate Tenacity Medium-Low Elongation	High Elong. High Energy to Break	High Tenacity Nylon	"E" Glass
Elongation to Break %	2.5-4	8±2	≥20	≥20	≥10
Tenacity, g/denier	≥14	≥10	≥6.5	≥8.0	≥3.0
Modulus, g/denier	≥550	≥300	≥150	≥40	≥250
Work to Break g-cm/den cm	≥0.3	≥0.50	~1.0	~1.3	≥0.2

Duplicate yarn samples of approximately one-half pound each were prepared at two levels of filament denier and two levels of yarn denier for each of the three types of X-500 fiber indicated above. The target filament and yarn deniers along with the approximate numbers of filaments desired in each yarn are shown below.

Desired Yarn Construction for Each of the Three Fiber Types

Nominal Yarn Denier	Nominal Filament Denier Type I	Type II	Type III	Approximate No. of Filaments
200	5	6	7	40-30
200	8	9	10	25-20
1050	5	6	7	200-150
1050	8	9	10	130-100

The fibers were spun as continuous filament yarns having the single filament characteristics and properties given in Table I and the untwisted "off the machine" yarn properties shown in Table II.

These yarns were then twisted to the desired turns per inch[1] with properties given in Table III. Only the initial modulus values of the yarns were calculated because the shape of the stress-strain curves of all samples showed that no break or yield point existed. Typical composite stress-strain curves for each yarn type are given as Figures 1 through 3.

A total of 26 bobbins of X-500 yarns was evaluated by the U.S. Army Natick Laboratories.[2] The sample identification and quantity of each bobbin submitted are given in Table IV.

B. Phase II - X-500 Ballistic Fabric

The objective of this phase of the work was to prepare 25 square yards of fabric from each of the three types of experimental high modulus organic fiber, X-500, characterized by the yarn samples of Phase I.[2]

1. Yarn Preparation

The yarns used in the preparation of the fabrics of Phase II were prepared in a scaled-up pilot unit patterned after the research equipment used for the preparation of the Phase I samples. The yarn properties of these fibers are given in Table V. The yarn denier of each fiber type was targeted at 1050, corresponding to the yarn denier used in the preparation of standard nylon ballistic fabric specified by Military Specification MIL-C-12369D(GL). The lower filament deniers of each of the three types of yarn prepared in Phase I were selected for the yarns to be used in fabric weaving. The physical properties of the "as spun" yarns agreed quite well with those of the corresponding sample yarns prepared for Phase I (Table II). The "as spun" yarns were given about the same level of twist as was used in the corresponding yarns of Phase I. The Type II yarn was twisted at a somewhat lower level (2.0 t.p.i.Z rather than 3.0 t.p.i.Z used previously) in order to achieve maximum yarn strength.[1,4] The average physical properties of the twisted yarns are given in Table VI. These properties are in general agreement with those of the Phase I yarns (Table III) except that a slightly higher elongation was targeted with small sacrifices in tenacity and modulus. This small trade-off in properties was intended to improve the weaving performance, particularly of the low elongation yarns.

2. Fabric Weaving

The recommended weave pattern for the fabrics was the 2 x 2 basket weave described by MIL-C-12369D(GL) with a small adjustment in yarn count to compensate for the higher fiber density of the X-500 compared to that of nylon.[3] A finished "off-the-loom" texture of 52 x 47 was targeted for all three fabric samples.

(a) Slashing and Beaming

The warp yarns were sized prior to beaming using the following formulation:

Total volume, 30 gal.
25 gal. water
5 gal. Orthocryl polyacrylic acid, 25% solids
Size temperature, 140°F
Over waxed after drying with Syncote A-30

The yarn was taken from a Sipp-Eastwood warping creel, through a Cocker Sample Slasher using steam heated drums (220°F) in the drier section and onto a Sipp-Eastwood beamer. The warp beams of Types I and III yarns (40.5 inches wide) were prepared in 18 sections using a total of 1944 ends. These warps were prepared before weaving was begun. An adjustment was made in beaming of the Type II yarn to compensate for a necessary change in the weave texture. Type II yarn was beamed 40.5 inches wide with the total ends reduced to 1782.

(b) Entering and Weaving

A Draper X-3 loom was used in the weaving of all fabric samples. The warp was entered using a straight draw-in on four harness to give a 2 x 2 basket weave with 2 ends weaving as one and 2 picks weaving as one. The Type III yarn was selected for weaving first because of the higher yarn elongation. It was initially entered with a 24/2/1 reed and a No. 45 picker gear to achieve a weave texture of 52 x 47 off the loom. Drag rolls were used on the loom to obtain maximum pickage. It was found, however, that the loom picker could not achieve 45 picks per inch with the 1050 denier filling yarn. To retain the same ratio of warp yarn to filling yarn, it was agreed to change the weave texture to 46 x 42.[5] The warp was re-entered using a 11/4/1 reed and a No. 40 picker gear. The fabric shrinkage coming off the loom was somewhat less than expected and a texture of 46 x 40 was obtained. Because of this change to give a looser fabric texture, the overall width was 42-1/2 inches rather than the planned 40 inches.

The Type II yarn was woven using the same loom conditions. As mentioned, the total warp ends were decreased during beaming to compensate for the change in texture. This produced a fabric 39-1/2 inches wide with a texture of 45 x 40.

The Type I yarn was entered using the same loom conditions of the preceeding types. However, this yarn because of its very low elongation, lacked the resilience needed to withstand the beating action of the reed during weaving. Excessive breaking

of warp ends occurred making it impossible to maintain sustained operation of the loom and resulting in fabric of poor quality. It was necessary to reduce the picks to achieve weaving performance.[5] A step-wise reduction in picks established 30 picks per inch as the maximum for sustained loom operation and reasonable quality fabric. This fabric came off the loom 44 inches wide and with a texture of 45 x 30.

3. Fabric Finishing

At the request of Natick Laboratories[3], approximately one-half of the yardage of each fabric sample was scoured using the following recommended procedure:

Open Jig
70 gal. water
12 lbs. TSPP (tetra-sodium pyrophosphate)
2.5 lbs. Triton X-100, adjust to pH 9-9.5
Start at 120°F, raise to 180°F
Hold at 180°F for one hour
Running water rinse to pH of 7.0
Dry at 225-250°F without tension
Eliminate heat setting

Prior to scouring the fabric samples, laboratory experiments were conducted to ascertain whether any damage to the fabric might result from the scouring. Sized warp yarns of each fiber type were scoured in laboratory glassware using formulations to simulate the above recommended procedure and a milder neutral scour. The physical properties of the sized yarns and each of the scoured yarns were measured using the Instron tester. These properties and the scour formulations are given in Table VII. The starting sized yarn was sampled during warp beaming and the particular yarn strands tested were selected at random from bundles of the scoured and unscoured yarns. Therefore, it is not likely that the actual test measurements were made on the same yarn strand. An exact comparison of the data of Table VII cannot be made, but must be viewed as a comparison of averages. It was concluded that no significant differences were shown between scour formulations; therefore, the recommended scour procedure was followed.

4. Fabric Testing

The Military Specification for Nylon Ballistic Cloth, MIL-C-12369D(GL) was used as the basis for all tests made on the X-500 fabrics. However, since these specifications were intended for use with commercial fabrics rather than highly experimental materials, some modifications were made to conserve fabric.[6]

(a) Complete tests were made only on the finished scoured fabric samples.

(b) Breaking strength and ultimate elongation were measured by the ravel strip method using 1-inch x 8-inch samples. Five specimens each of the greige and finished fabrics were tested.

(c) Sample size used for the boiling water shrinkage test was reduced to 10 inches x 10 inches and only one specimen each from the greige and finished fabrics was tested.

In addition, the breaking tenacity defined as pounds per inch per ounces per square yard was calculated from the breaking strength and fabric weight. This was deemed necessary to compare the fabric strengths on an equal weight basis. Identical test data were also measured from the nylon ballistic fabric supplied by the contracting officer for comparison with the X-500 fabrics.

All test data are given in Table VIII. Comparison of the strength data shows the X-500 Type I fabric to be somewhat stronger than the nylon fabric, the Type II about equivalent and the Type III substantially weaker on an equal weight basis. All X-500 fabrics showed lower elongation values than the nylon. X-500 fabrics have no measurable shrinkage in boiling water.

The fabric samples, six fabrics totaling 75 sq. yds. comprising Phase II of this contract were shipped to the U.S. Army Natick Laboratories for ballistic evaluation.[7]

C. <u>Phase III - X-500 Ballistic Felt</u>

The objective of this phase of the work was to prepare needle punched felts (5 sq. yds. each) from Type II and Type III of Monsanto's experimental high modulus organic fiber, X-500. Interim Purchase Description IP/DES-S-53-7[8] was used as a guideline for the preparation and testing of the X-500 felts. It had been observed during Monsanto's evaluation of X-500 fiber that Type I X-500 fiber having only 2-3% elongation was too brittle to process into the crimped staple fiber necessary for the formation of non-woven fabrics. In lieu of the Type I felts, a 2 lb. package of pilot plant spun continuous filament 1050 denier yarn of Type I X-500 fiber was submitted. Research samples of all three types of the X-500 fiber were previously delivered as Phase I.[2]

1. Yarn Preparation

The X-500 yarns used in preparation of the felts of Phase III were prepared during the same pilot plant operations described in the preparation of the Phase II fabrics.[7] Table V gives the average physical properties of these yarns. Only yarns of Type II and Type III were converted into felts.

2. Crimping and Cutting

A Turbo tow crimper operating on the steam stuffer box principle was used to crimp both types of yarn. Multiple yarn ends were brought together from a creel using spring tension regulators to maintain uniform yarn tension on all ends. The combined yarn ends (tow) was passed through a finish dip bath and into the crimper. Machine operating conditions were as follows:

Feed Denier	20,000 ± 5,000
Crimp Speed (fpm)	150
Roll Pressure (lbs.)	600
Gate Setting	0
Steam Pressure (psig)	5
Crimps per inch	6
Finish Applied (%)	0.25 (RF-132)

The crimped tow was heat set at 140°C with a residence time of 9 minutes. A continuous feed conveyor belt oven was used. The crimped, heat set tow appeared to have good crimp elasticity and very little static build-up. It was cut into nominal 4-inch staple using a Gru Gru type cutter manufactured by the Teijin Seiki Company of Japan. Forced air was applied to the exiting staple to separate the fiber bundles. No static build-up was observed during the cutting operation. The properties of the crimped fiber staple are given in Table IX.

3. Carding and Batt Formation

Staple carding and batt formation was carried out by Textile Research Services, Inc. of Raleigh, North Carolina. A 54-inch garnet card was used. The X-500 stapel fiber was hand-fed onto the feed apron across the center 30 inches of the card. Weighed quantities (10 ozs. of Type III and 12 ozs. of Type II) of staple were uniformly spread onto the feed apron in order to assure uniform loading on the card. A take-up device consisting of a rotating piece of 3/4-inch plywood 36 x 48 inches mounted on a suitable frame was used to form layers of carded web into batts of the proper weight. The 36 inches wide

card web (0.5 oz./sq. yd) was taken from the doff roll and taped onto the plywood board. The board was rotated to place four layers of web onto the board. The batt, 36 inches wide and 72 inches long, was removed by cutting along one edge. This batt was then folded in thirds to give a batt 12 inches wide by 72 inches long, weighing approximately 6 oz./sq. yd. and suitable for needle punching.

In carding the Type III fiber, it was found that the card web lacked sufficient cohesion to hold together during take-up on the rotating board. Several organic adhesives, sprayed on the staple fiber prior to carding, were tried in attempts to increase the fiber cohesion. None was satisfactory. A colloidal silica dispersion, Syton DS-50 (Monsanto Company), was found satisfactory when sprayed on the staple fiber. Adequate cohesion was achieved without excessive loading or sticking on the card. Syton was used in the preparation of all Type III batts.

The Type II fiber performed quite satisfactorily on the card without the use of an adhesive additive. Most of the Type II batts were prepared without Syton; however, a few were made with Syton to serve as a basis for comparing the effect of Syton.

4. Needle Punching

A 12-inch wide needle loom manufactured by the James Hunter Machine Company was used in the preparation of all felt samples. A high density needle board (90 needles/ln. inch) was prepared using 15 x 18 x 32 x 3-1/2 RB needles (Torrington No. 77-1202-00-1) as recommended by NLABS. The loom was set for a penetration of 1/2-inch to assure that all barbs would be working in the batts. The advance was set at 9/16-inch giving 165 penetrations per square inch. Sample batts were needled with a single pass, then two batts were re-needled together in a second pass. The layers could be separated and it was thought that a somewhat higher density needling was necessary. The advance was reduced to 7/16-inch (190 penetrations per square inch) resulting in more tightly bonded layers. All batts of Types II and III fibers were then needled with these conditions. The uniformity of the needled batts appeared good when inspected over a light box.

5. Hot Pressing

A two-roll, oil heated calender was used to compact the felts after needling. Experiments were conducted at various temperatures and roll pressures to find the best conditions for pressing. Best compaction was obtained at 255°F and 3,770

lb. per linear inch (150 psig) roll pressure. At higher temperatures fiber filaments fused on the surfaces. A pressure of 150 psig was considered to be near the maximum safe operating pressure for the equipment. Lower pressures resulted in less compaction. It was noted that the calendered felts increased in thickness on standing. This is thought to be due to the high modulus and high distortion temperature of the X-500 fiber.

The final calendered felts measured about 13 inches wide and 80-84 inches long. About half of the calendered samples were trimmed to 12 inches by 72 inches for weight and thickness measurements. These measured values are given in Table X.

Eight pieces of felt each of Type II and Type III X-500 fibers, about 5.5 sq. yds. each, were submitted for ballistic testing. Shipment of the felts and a two pound bobbin of Type I X-500 yarn (Table V) comprising Phase III of this contract were made to the U.S. Army Natick Laboratories for ballistic evaluation.[9]

D. Phase IV - X-500 Ballistic Laminates

The objective of this phase was to prepare laminate panels of X-500 fabrics for evaluation as ballistic material. The panels were constructed using Limited Purchase Description LP/P, DES 42-69[10] as a guideline for preparation and testing. A variety of composition and structure variables was incorporated in the panels to judge the effects of these variables in combination with fabric properties on ballistic performance.

1. Fabric Weaving

The same fabric construction used to prepare the ballistic fabrics of Phase II was selected for preparation of the X-500 fabric-resin laminates.[4] Small additional yardage of fabric of all three X-500 types was woven during the preparation of the fabrics of Phase II. These fabrics (Table VIII) were used in the preparation of the initial exploratory panels.

Ballistic data obtained from evaluation of the exploratory laminated panels prepared from the three types of X-500 fabric indicated scoured, Type III to be the preferred fabric for preparation of a series of test laminated panels.[11] Additional fabric was woven from Type III yarn using the same weave design used for the Type III fabric prepared for the Phase II fabrics. The warp preparation and weaving conditions were as follows:

Warp Length	44 yds.
Total Ends	1782
Draw	Straight
Harness	4 + 4
Size Composition	5 gal. Orthocryl 25, 25 gal. water; Over wax—Syncote—A-30
% Size Pick-up	2.94
Reed	11/4/1
Pick Gear	40
Off Loom Width	39.0
Off Loom Construction	45 x 40
Yds. Woven	35
Piece #	8728

Drag Rolls were used on loom to obtain required pickage

The greige fabric was scoured using the same formulation and procedure previously reccommended and used for the Phase II fabrics.(3)

2. Preparation of Laminates

The vacuum bag technique was used for the preparation of all of the X-500 experimental laminates of Phase IV.(10) The vacuum bag assembly used is illustrated by Figure 4. The X-500 fabrics were precut into squares approximately one inch larger than the desired size of the laminated panel. The weight of fabric required for each laminate was calculated from the desired areal density and fabric loading values. The number of fabric layers weighing nearest to the desired total fabric weight was determined and the actual weight of these layers was measured. The weight of resin required for each laminate was calculated from the actual fabric weight and the desired fabric loading using simple proportions. Each layer of fabric was coated with the proportionate amount of the total resin weight. The resin impregnated fabric swatches were layered on the vacuum bag platen as indicated in Figure 4. No effort was made to orient the warp or fill direction of the fabric swatches in the lay-up. Random lay-up was used for all laminate preparations. Multiple laminates were fabricated in a single vacuum bag lay-up when practical to do so. The vacuum bag assembly was then sealed and vacuum tested.

A large cylindrical autoclave measuring 36 inches by 60 inches inside dimensions, manufactured by the Erie City Iron Works of Erie, Pa., was used to cure all laminates prepared. This autoclave is pictured in Figure 5. The desired curing temperature and pressure were preset and controlled automatically. The autoclave was preheated + near the desired curing temperature prior to loading. The platen vacuum bag assembly was placed in the autoclave and attached to the vacuum line.

The bag was evacuated to 25 inches of mercury and tested prior to closing the autoclave. The vacuum on the bag was reduced to about 5 inches of mercury when the autoclave was pressurized and was maintained at the vacuum level during the curing cycle. The curing cycle was varied with the resin composition used. Most of the laminate samples were prepared using Rohm and Haas resin P-43, an unsaturated polyester formulation. The P-43 resin was modified with styrene monomer, usually 10 parts to 100 parts of resin, to impart better wetting of the fabric. However, styrene concentration was one of the controlled variables studied in the resin composition. The standard curing cycle used for all laminates prepared with P-43 resin was 30 minutes at 250°F and 40 psi pressure. The pressure and temperature usually reached the desired level in about 5 minutes. The curing time was measured from that time. The autoclave was cooled with forced air for 15 minutes after completion of the curing cycle and prior to opening. The cured laminates were removed from the autoclave and vacuum bag assembly, weighed, and trimmed to the desired size using a conventional circular bench saw. Care was taken to maintain the saw blades in a sharp condition to prevent fraying of the fabric edges.

A total of 10 exploratory fabric laminates were fabricated to guide the selection of fabric type, fabric loading, fabric finish and resin composition. All of these laminates were 12 x 12 inches with a nominal areal density of 1.25 pounds per square foot. The selection of variables studied was agreed upon by NLABS and the Monsanto Research Corporation.[12,17] The composition and properties of these exploratory panels are given in Table XI.

Ballistic evaluation data obtained from these samples by NLABS (Table XIV) was used to establish the conditions for preparation of a series of 25 test laminates.[11] These laminates were prepared using only scoured, Type III X-500 fabric with P-43 resin. The variables incorporated into the test series included the following:

Panel Size
Areal Density
Fabric Loading
Styrene Content of Resin

Table XII outlines the desired laminate construction and composition.

The 60% level of fabric loading resulted in the best laminates judged by appearance. The 80% fabric loading level did not provide sufficient resin for adequate wetting of the fabric and resulted in apparent dry spots. The 40% level of fabric loading provided excess resin, some of which tended to bleed out during curing. Even curing at lower pressures did not prevent bleed out, but only resulted in greater unevenness and residual bubbles in the cured laminate. All laminate samples were cured at the standardized conditions previously described. Table XIII shows the properties of the 25 test fabric-resin laminates supplied to the NLABS for ballistic evaluation. Table XV summarizes the ballistic data obtained.

3. Laminate Tests[10]

(a) Areal Density

The areal density of the finished laminate was determined by careful measurement and calculation of the area of the trimmed panel. The area value in square feet was divided into the weight of the panel measured to the nearest 1/100 pounds to give the areal density in pounds per square foot.

(b) Thickness

The thickness of the laminated panels was measured using a deep throat dial calipers reading in 1/1000-inch. Four measurements were made along each side of the panel at depths of one and two inches. The resulting 16 measurements were averaged to give the recorded thickness value.

(c) Fabric Loading

The nominal fabric-resin ratio of the laminate panels was determined from the actual weights of the fabric and resin components applied during fabrication of the laminate. Corrected values of fabric loading were obtained by dividing the actual weight of fabric used, by the total weight of the cured laminate prior to trimming. Thus, resin lost during curing by evaporation or bleeding was not considered in the measured value.

E. Results and Conclusions

This contractor's obligation was to prepare three types of X-500 fibers and fabricate them into the yarns, fabrics, felts and laminates described. The ballistic testing of the resulting materials was supervised by NLABS.

The aim in investigating fabric structures prepared from the same family of fibers, but differing widely in properties such as strength, elongation and modulus was to establish the importance of these various properties in furnishing good ballistic candidates and to help establish a constitutive equation relating ballistic properties to measurable mechanical properties. The actual ballistic results for the three fabrics are given in Table XIV.

The results are meaningful both by comparison within themselves and by comparison to other commonly tested materials. Within the X-500 family the higher tenacity higher modulus members (Types I and II) are the poorest ballistically. There is no significant difference between the Type I and Type II results despite the tradeoff that occurred between tenacity and modulus on the one hand and elongation on the other (see Table V) in moving from one to the other. The Type III yarns with the lowest tenacity and modulus but the highest work-to-break gave the best results. The ballistic values obtained with the Type I and Type II materials are quite comparable to those expected from a good glass fabric.

Needle-punched felts prepared from X-500 fibers gave poor ballistic values. This was not suprising as similar results have been obtained whenever low-elongation materials (i.e., glass) have been used for felt formation. However, better results had been anticipated for the Type III X-500 felts than were obtained.

The other ballistic use for an organic fiber with glass-like properties is in the production of laminates. Table XI, XII and XIII show the wide variations used in the preparation of laminates. The parameters investigated included percent fabric loading, resin type and fiber type. Some representative ballistic results obtained with these laminates are shown in Table XV.

In all cases, the ballistic results of the laminates were poor, but those using the Type III fabric were better than those of the Types I or II. The rating of poor was given by comparison with fiberglass laminates. In all cases, the ballistic values obtained for the laminates were far below those characteristic of glass laminates known as Doron. One possible reason for this behavior is the poor lateral strength compared to the longitudinal strength. Glass fibers are more nearly isotropic, whereas, organic polymeric fibers tend to be anisotropic due to the drawing operation. Although the structure of the X-500 chemical entity is proprietary it may be assumed that there is less intermolecular attraction than with polymers such as the usual nylons.

In laminates the role of fiber properties is complicated by the interaction with resin and the interlaminar forces. In the past 20 years of investigation no organic fibrous material has been found which in laminate form possessed ballistic resistance superior to glass. The X-500 fibers appeared to have some of the necessary features for competing with glass (high modulus, high strength) but failed to perform satisfactorily. The answer to this failure may lie in the micromechanics of laminate structures including such features as delamination of the individual fibers. This in turn may depend upon surface differences between an inorganic material such as glass and an organic material such as the X-500 fibers.

III. REFERENCES

1. M. R. Lilyquist, Monsanto Research Corporation, Durham, North Carolina, to M. C. Henry, U. S. Army Natick Laboratories, letter dated 2 May 1969.

2. M. R. Lilyquist, Monsanto Research Corporation, Durham, North Carolina, Status Report No. 1, Contract DAAG17-69-C-0079, "Experimental Organic Fiber Materials for Personnel Armor: Phase 1," 28 May 1969.

3. M. C. Henry, NLABS to M. R. Lilyquist, MRC, letter dated 12 August 1969.

4. M. R. Lilyquist to R. C. Laible, NLABS letter dated 4 November 1969.

5. R. C. Laible, NLABS letter dated 19 November 1969.

6. R. C. Laible, NLABS letter dated 3 December 1969.

7. Status Report No. 2, Contract DAAG17-69-C-0079, "Experimental Organic Fiber Materials for Personnel Armor: Phase II," 15 December 1969.

8. Interim Purchase Description for Felt, Ballistic, Nylon No. IP/DES-S-53-7, 26 October 1967, prepared by U.S. Army Natick Laboratories (GL).

9. M. R. Lilyquist, Monsanto Research Corporation, Status Report No. 3, Contract DAAG17-69-C-0079, "Experimental Organic Fiber Materials for Personnel Armor: Phase III," 23 February 1970.

10. Interim Purchase Description for Body Armor, Small Arms Protective, Aircrewman No. LP/P DES 42-69, NLABS 19 November 1969.

11. R. C. Laible, NLABS to M. R. Lilyquist, MRC, letter dated 13 November 1970.

12. M. C. Henry, NLABS to M. R. Lilyquist, MRC, letter dated 27 March 1970.

13. M. R. Lilyquist, MRC to M. C. Henry, NLABS, letter dated 26 May 1970.

14. M. R. Lilyquist, MRC to R. C. Laible, NLABS letter dated 12 August 1970.

15. To R. C. Laible, NLABS letter dated 28 August 1970.

16. To R. C. Laible, NLABS letter dated 25 September 1970.

17. To R. C. Laible, NLABS letter dated 29 October 1970.

TABLE I

X-500 SINGLE FILAMENT PROPERTIES[a]

Identification		Property[b]					
Type	Sample No.	Denier Per Fil.	Tenacity g/den.	Elong. %	Modulus, Mi g/den.	Sonic Modulus g/den.	Work-to-break g-cm/den.-cm.
I	1	4.5	16.3	3.2	736	790	0.33
I	2	4.8	14.6	3.2	632	880	0.30
I	3	8.0	14.4	3.8	556	883	0.34
I	4	8.3	14.5	3.2	645	803	0.31
II	5	6.2	10.2	9.5	534	525	0.76
II	6	5.5	11.0	8.3	430	497	0.73
II	7	7.4	11.7	6.8	387	577	0.58
II	8	8.7	10.2	6.4	396	598	0.54
III	9	7.1	7.4	21.2	275	383	1.36
III	10	7.1	8.3	22.9	224	349	1.60
III	11	9.1	8.2	18.0	231	362	1.12
III	12	10.4	7.1	22.9	218	288	1.36

a Measured on an Instron Tester, 1-inch gauge length, 100% extension per min.

b Average values of 20 breaks

TABLE II

X-500 UNTWISTED YARN PROPERTIES[a]

Identification		Property					
Type	Sample No.	Denier of Yarn	No. of Filaments	Tenacity g/den.	Elong. %	Modulus, Mi g/den.	Work-to-break g-cm/den-cm
I	1	213	40	10.1	2.0	754	0.15
I	2	1048	200	9.8	1.6	738	0.11
I	3	220	25	9.1	1.8	706	0.11
I	4	1124	130	8.9	2.0	646	0.11
II	5	193	30	9.4	6.7	373	0.48
II	6	1032	180	10.0	6.8	365	0.50
II	7	186	20	9.0	3.4	508	0.22
II	8	1126	120	8.6	3.7	466	0.28
III	9	215	30	7.2	14.6	385	0.90
III	10	1051	150	7.0	7.3	274	0.41
III	11	200	20	7.2	7.4	330	0.43
III	12	995	100	6.2	14.5	213	0.75

[a] Measured on an Instron Tester at 10 inches gauge length at 5% extension per minute for Type I yarns and 100% extension per minute for Types II and III yarns. Average of 10 breaks per sample.

TABLE III

X-500 TWISTED YARN PROPERTIES[a]

Identification Type	Identification Sample	Denier of Yarn	Twist t.p.i.Z	Break Strength lbs	Tenacity g/den.	Elong. %	Modulus, Mi g/den.	Work-to-break g-cm/den-cm
I	1	212	2.4	5.56[b]	12.0	1.92	733	0.13
	1 (suppl)	360	0.7	--	12.6	2.2	650	--
I	2	1096	1.0	22.0[b]	9.1	1.94	621	0.11
I	3	219	2.3	5.19[b]	10.8	1.82	698	0.11
I	4	1130	1.0	25.8[b]	10.4	1.93	665	0.12
II	5	192	3.9	3.50[c]	8.4	5.1	384	0.32
II	6	1082	3.0	19.9[c]	8.4	5.7	352	0.35
II	7	178	3.9	3.57[c]	9.2	3.9	460	0.24
II	8	1127	3.0	21.0[c]	8.5	4.4	381	0.26
III	9	216	3.9	3.0[d]	6.3	11.3	270	0.60
III	10	1081	3.9	15.0[d]	6.3	9.6	228	0.49
III	11	200	4.0	2.9[d]	6.7	7.8	280	0.41
III	12	1026	4.0	13.9[d]	6.2	15.5	208	0.78

[a] Instron Tester measurements, average of 20 breaks, 10 inch gauge length
[b] Strain rate: 5% extension per min.
[c] Strain rate: 10% extension per min.
[d] Strain rate: 20% extension per min.

TABLE IV

PHASE I, X-500 FIBER SAMPLES

Fiber Type	Sample No.	Net Weight in Grams Bobbin "A"	Bobbin "B"	Total
I	1	385	120*	505
I	2	448	159	607
I	3	286	137 155(C)	578
I	4	360	116	476
II	5	183	234	417
II	6	253	238	491
II	7	196	222	418
II	8	228	230	458
III	9	112	412	524
III	10	305	156	461
III	11	254	269	523
III	12	219	261	480
			Total Net Weight	5938 (13.08 lbs.)

* Supplemental sample delivered to Mr. Roy Laible 21 May 1969.

TABLE V

PHYSICAL PROPERTIES OF "AS SPUN" X-500 PILOT YARNS

Yarn Type	Denier No. fils.	Scott IP-4 Tenacity gpd	Scott IP-4 Tester[1] Elong. %	Instron Tester[2] Tenacity gpd	Instron Tester[2] Elong. %	Instron Tester[2] Modulus gpd	Work-to-Break gm-cm/den-cm
I	1056/200	10.3	1.9	10.7	2.54	600	0.178
II	1036/160	8.03	5.2	7.5	4.42	389	0.259
III	1086/160	5.5	18.5	4.9	17.0	186	0.694

1 Control test, measured on each spun bobbin, average of approximately 70 bobbins of each type.

2 Average of 5 breaks on each of 10 samples randomly selected from each yarn type using 10 inches gauge length with 10% extension per minute for Type I yarns and 100% extension per minute for Types II and III yarns.

TABLE VI

PHYSICAL PROPERTIES OF TWISTED X-500 PILOT YARNS[1]

Yarn Type	Twist Level t.p.i. Z	Denier	Instron Tester[2] Tenacity gpd	Elong. %	Modulus gpd
I	1.0	1090	10.1	2.36	532
II	2.0	1038	7.6	4.5	314
III	3.8	1109	4.8	19.2	163

1. Average of 15 sample bobbins of each yarn type randomly selected.

2. Average of 5 breaks on each sample using 10 inches gauge length with 10% extension per minute for Type I yarn and 100% extension per minute for Types II and III yarns.

TABLE VII

PHYSICAL PROPERTIES OF SIZED AND SCOURED X-500 WARP YARNS

Property	Yarn Type I	Yarn Type II	Yarn Type III
Twist, t.p.i.	1.0	2.0	3.8
Denier (original yarn)	1050	1050	1050
Sized Yarns			
Tenacity, gpd	11.2	7.3	5.2
Elong.,%	3.0	5.0	16
Modulus, gpd	432	308	161
Scour A			
Tenacity, gpd	10.5	6.7	5.0
Elong.,%	3.0	5.0	14
Modulus, gpd	450	257	157
Scour B			
Tenacity, gpd	10.9	6.8	4.8
Elong.,%	3.0	5.0	15
Modulus, gpd	491	240	142

Sizing Formulation: 5 gal. orthocryl (polyacrylic acid)
25% solids
25 gal. water
Overwax with Syncote A-30

Scour A Formulation: 1 gm/liter Triton X-100
180°F for 20 min. in lab ware
Dried at 225-250°F

Scour B Formulation: 2 gm/liter TSPP (tetra sodium pyrophosphate)
1/2 gm/liter Triton X-100
Neutralize to pH 9.5
180°F for 20 min. in lab ware
Rinse to pH 7
Dried at 225-250°F

TABLE VIII

PHYSICAL PROPERTIES OF X-500 EXPERIMENTAL FABRICS

Property	X-500 Yarn Type I Greige	I Finished	II Greige	II Finished	III Greige	III Finished	Nylon Ballistic Fabric Control
Overall width, in.	44	44	39.5	39.5	42.5	42.5	48
Weight/sq.yd., oz.	--	10.9	--	11.8	--	12.4	14.2
Yarns/inch							
Warp	45	45	45	45	46	45	49
Filling	30	31	40	39	40	40	43
Break Strength,[a] lbs/in.							
Warp	852	876	663	741	524	533	944
Filling	701	675	681	681	490	521	827
Break Tenacity[b] lbs/in/oz sq. yd							
Warp	--	80.0	--	62.7	--	42.9	66.6
Filling	--	61.6	--	57.6	--	42.0	58.5
Ultimate Elong.%[c]							
Warp	8.0	7.6	12.3	13.1	28.8	28.3	46.7
Filling	4.9	2.9	8.8	8.6	25.3	22.6	39.7
Shrinkage in Boiling Water,%[d]							
Warp	nil	nil	nil	nil	nil	nil	3.8
Filling	nil	nil	nil	nil	nil	nil	1.56

Test methods described in MIL-C-12369D(GL) unless otherwise noted

[a] Tested by ravel strip method using 1 x 8 inch specimen, average of five breaks per sample.

[b] Not included in MIL-C-12369D(GL).

[c] Tested by ravel strip method.

[d] Measured from a single specimen 10 x 10 inches marked to 8 x 8 inches.

TABLE IX

PHYSICAL PROPERTIES OF X-500 CRIMPED FIBER STAPLE

				Single Filament Instron Properties*			
Fiber Type	Nominal Crimps/in.	Staple Length, in.	Denier per filament	Tenacity gpd	Elong. %	Modulus gpd	Work-to-Break gm-cm/den-cm
II	6-8	4.20	6.50	8.42	15.0	248	1.03
III	6-8	4.15	6.60	6.19	23.0	151	1.11

*Average of 20 breaks on filaments taken at random from cut staple, using 1 inch gauge length and 100% extension per minute.

TABLE X

PROPERTIES OF NEEDLE PUNCHED FELTS

X-500 Fiber Type	Felt Weight oz./sq. yd	Thickness After Pressing, mils	Comments
II	14.4	130 ± 20	No adhesive on staple fiber
II	14.1	110 ± 20	No adhesive on staple fiber
II	14.1	120 ± 10	No adhesive on staple fiber
II	12.8	80 ± 10	Syton sprayed on staple fiber
III	12.5	80 ± 20	Syton sprayed on staple fiber
III	11.7	80 ± 10	Syton sprayed on staple fiber
III	10.9	80 ± 15	Syton sprayed on staple fiber

TABLE XI

X-500 EXPLORATORY FABRIC-RESIN LAMINATED PANELS

Variable/Property	Panel Sample Number								
	IV-1-A	IV-1-B	IV-1-C	IV-2-A	IV-2-B	IV-3-A	IV-3-B	IV-3-C	IV-4-A
Fabric Type	I	II	III	II	II	II	II	II	II
Fabric Finish	Scoured	Scoured	Scoured	Greige	2% mineral oil	Greige	Greige	Greige	Greige
Fabric Loading,%	62.8	64	62.1	74	73.5	80	79.6	80	41
No. Fabric Layers	9	8	8	11	11	12	12	12	6
Resin	P-43	P-43	P-43	P-43	P-43	Epon 828-DTA	Lexan Polycarbonate	Phenolic SC-1008	Epon 828-DTA
Styrene Modifier, pph	10	10	10	10	10	--	--	--	--
Cure Temperature, °F	250	250	250	250	250	70	275°C→ 240°C	162°C	70
Pressure, psi	40	40	40	40	40	25" Hg	20	30	25" Hg
Time, min.	30	30	30	30	30	120	15 → 240	16 hrs	120
Areal Density, lbs/ft^2	1.14	1.06	1.20	1.24	1.24	1.23	1.23	1.23	1.24

TABLE XII

X-500 FABRIC-RESIN LAMINATES

Nominal Areal, Density lbs/sq.ft.	Sample Size in.	Fabric Loading, %	Number of Samples
1.25	12 x 12	60	3 - with standard P-43 resin
		60	2 - with high styrene content P-43 resin
		60	2 - with low styrene content P-43 resin
2.30	12 x 12	60	2 - with standard P-43 resin
		60	1 - with high styrene content P-43 resin
2.30	9 x 9	80	5 specimens, one of which will use high styrene P-43 and one low styrene content P-43 and three regular P-43 resin
2.30	9 x 9	60	5 specimens, one of which will use high styrene P-43 and one low styrene content P-43 and three regular P-43 resin
2.30	9 x 9	40	5 specimens, one of which will use high styrene P-43 and one low styrene content P-43 and three regular P-43 resin

TABLE XIII

PROPERTIES OF TYPE III X-500 FABRIC-RESIN LAMINATES

Sample No.	Sample Size, in.	Fabric Loading, %	No. Fabric Layers	P-43 Resin PPh Styrene	Areal Density lbs/sq. ft. Target	Areal Density lbs/sq. ft. Actual	Thickness, in.
IV-5-1	12 x 12	59.7	8	10	1.25	1.12	0.174
IV-5-2	12 x 12	59.7	8	10	1.25	1.12	0.173
IV-5-3	12 x 12	59.7	8	10	1.25	1.12	0.173
IV-5-4	12 x 12	60.4	8	15	1.25	1.12	0.184
IV-5-5	12 x 12	60.4	8	15	1.25	1.10	0.183
IV-5-6	12 x 12	60.2	8	5	1.25	1.12	0.172
IV-5-7	12 x 12	60.2	8	5	1.25	1.12	0.169
IV-5-8	12 x 12	60.5	15	10	2.30	2.12	0.316
IV-5-9	12 x 12	60.5	15	10	2.30	2.12	0.314
IV-5-10	12 x 12	59.7	15	15	2.30	2.18	0.323
IV-5-11	9 x 9	80.2	22	10	2.30	2.32	0.456
IV-5-12	9 x 9	80.2	22	10	2.30	2.32	0.453
IV-5-13	9 x 9	80.2	22	10	2.30	2.32	0.459
IV-5-14	9 x 9	79.8	22	15	2.30	2.53	0.460
IV-5-15	9 x 9	79.6	22	5	2.30	2.43	0.450
IV-5-16	9 x 9	60.0	14	10	2.30	2.0	0.299
IV-5-17	9 x 9	60.0	14	10	2.30	2.0	0.304
IV-5-18	9 x 9	60.0	14	10	2.30	2.0	0.299
IV-5-19	9 x 9	60.1	16	15	2.30	2.32	0.353
IV-5-20	9 x 9	60.2	16	5	2.30	2.32	0.352
IV-5-21	9 x 9	41.1	11	10	2.30	2.0	0.298
IV-5-22	9 x 9	41.1	11	10	2.30	2.0	0.308
IV-5-23	9 x 9	41.1	11	10	2.30	1.9	0.300
IV-5-24	9 x 9	41.0	11	15	2.30	1.7	0.257
IV-5-25	9 x 9	41.4	11	5	2.30	2.0	0.309

TABLE XIV

BALLISTIC RESULTS FOR THREE TYPES OF X-500 FABRICS

Fiber Type	Areal Density (oz/sq. ft)	No. Plies	State	V50 (ft/sec)
I	18.4	15	Scoured	1070
	18.6	15	Greige	938
	11.1	9	Scoured	888
II	18.6	14	Greige	854
	18.6	14	Scoured	1074
	10.7	8	Scoured	830
III	19.2	13	Scoured	1244
	18.4	13	Greige	1132
	11.6	8	Scoured	998

TABLE XV

BALLISTIC RESULTS FOR X-500 FABRIC LAMINATES

No. Plies	Type Fabric	Loading,%	Areal Density, oz/sq. ft.	Resin	V50 ft/sec
12	II	60	19.7	Epoxy, 828	649
12	II	60	19.7	Phenolic, SC-1008	511
12	II	60	19.7	Polycarbonate	491
12	III	60	19.2	Polyester P-43 5pph Styrene	679
12	III	60	19.1	Polyester P-43 10pph Styrene	673
12	III	60	18.3	Polyester P-43 15pph Styrene	659
12	III	40	34.0	Polyester P-43 5pph Styrene	1043
15	III	60	39.3	Polyester P-43 5pph Styrene	1185
14	III	60	33.8	Polyester P-43 10pph Styrene	1052
15	III	60	35.9	Polyester P-43 15pph Styrene	1112
15	III	60	35.0	Polyester P-43 10pph Styrene	1118
22	III	80	40.1	Polyester P-43 10pph Styrene	1373

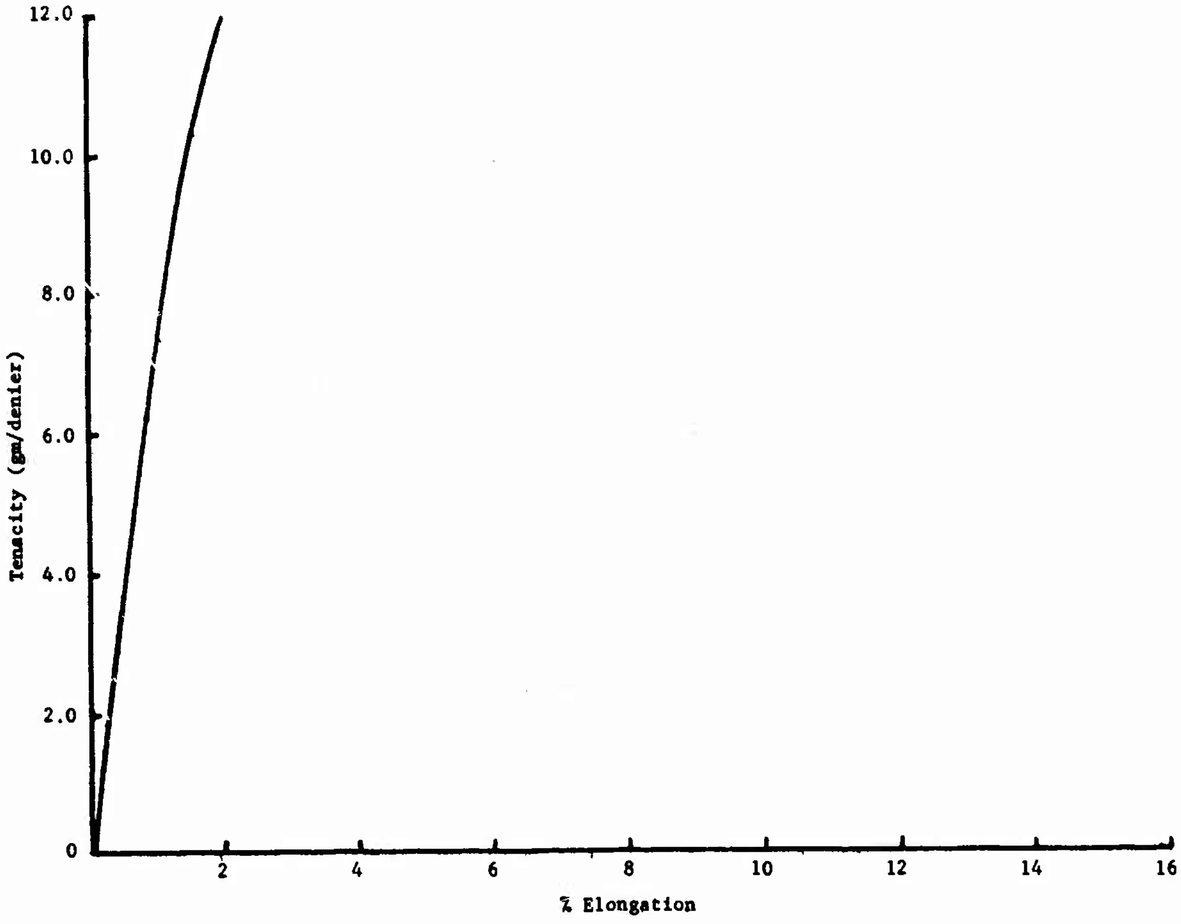

Figure 1. Stress-Strain Curve of Type I X-500 Fiber

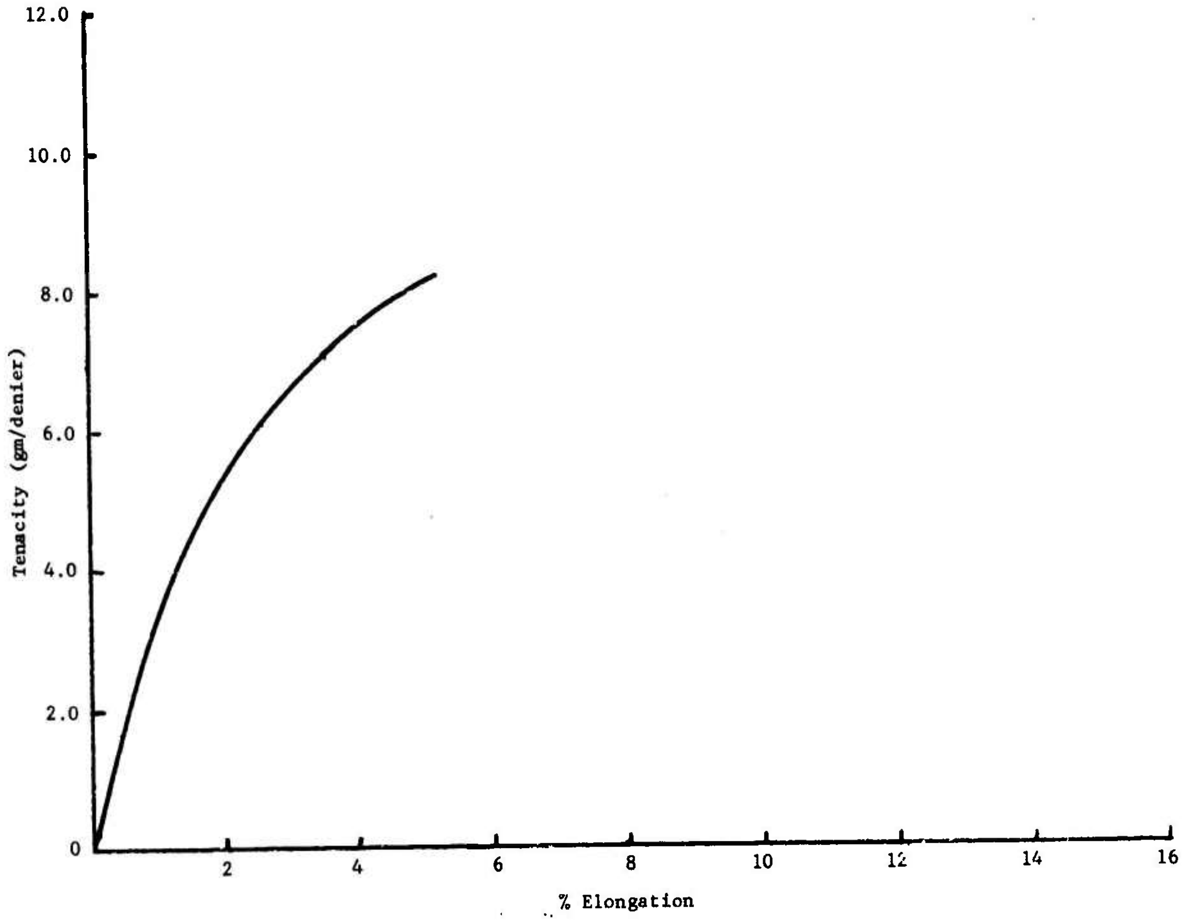

Figure 2. Stress-Strain Curve of Type II X-500 Fiber

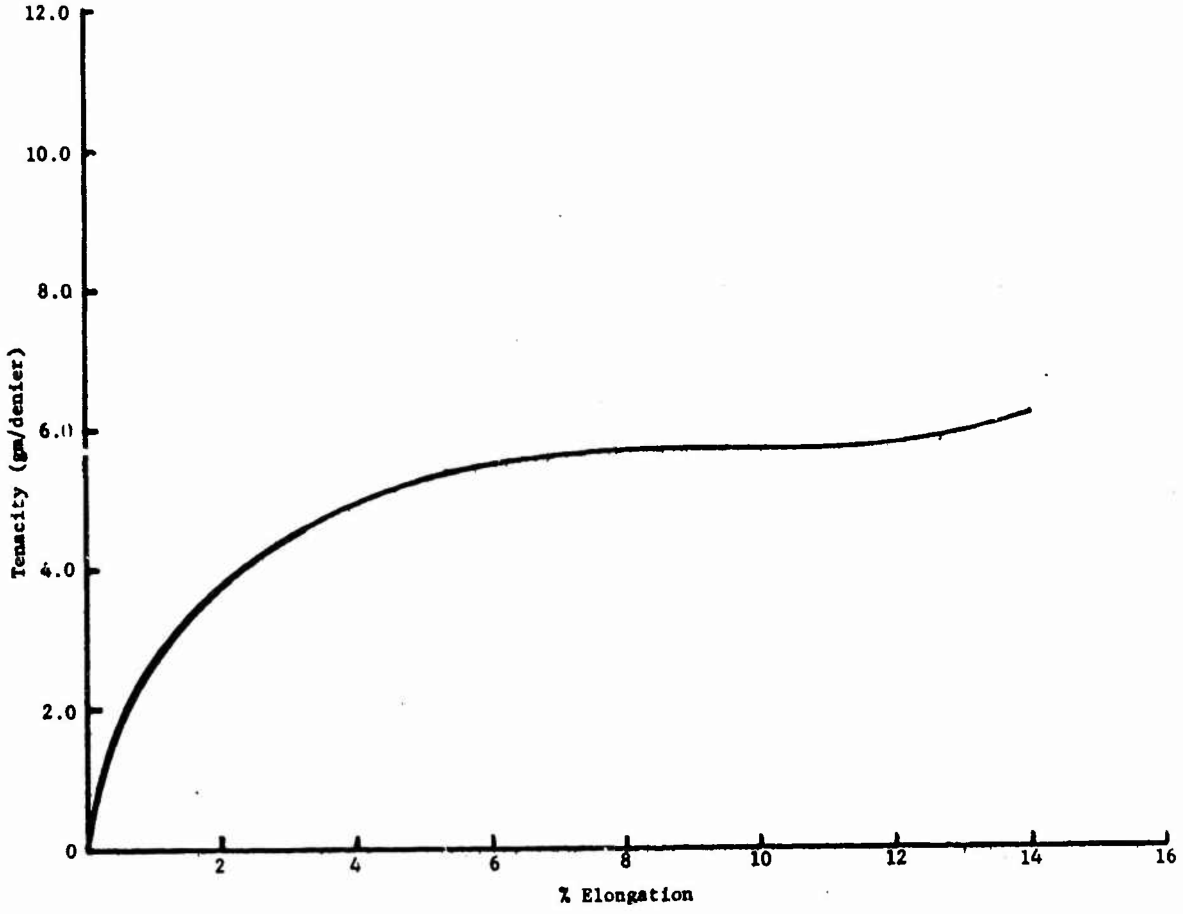

Figure 3. Stress-Strain Curve of Type III X-500 Fiber

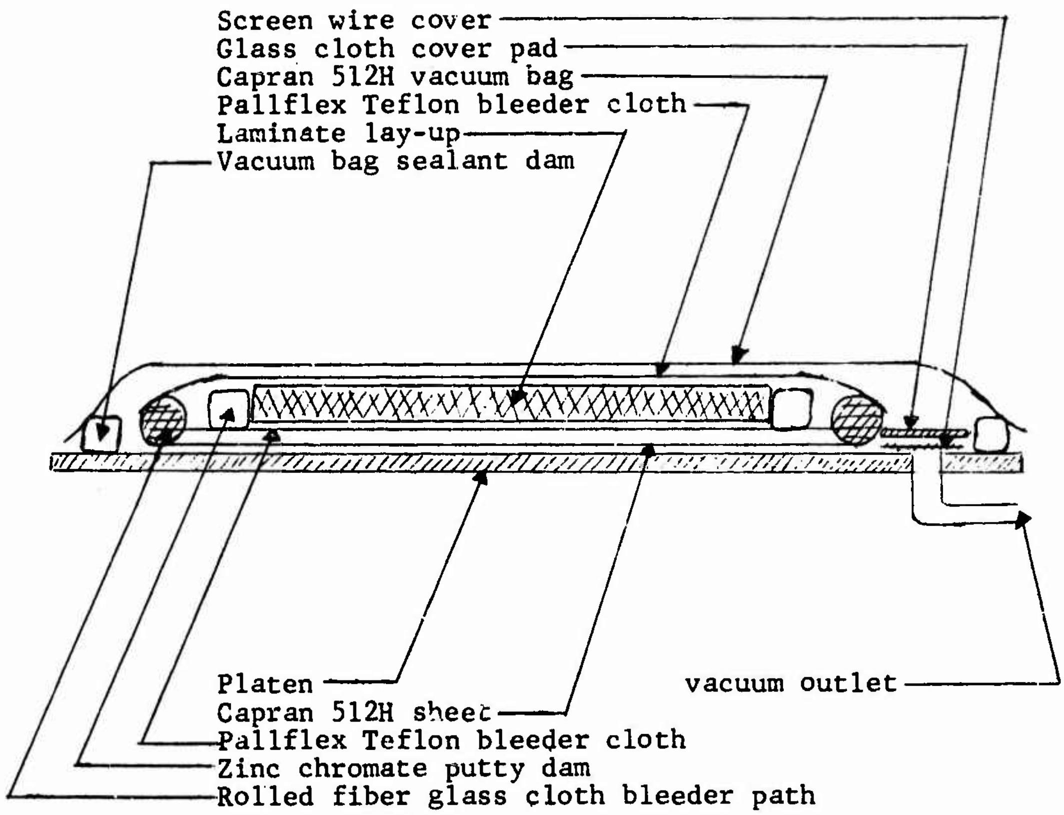

Figure 4. Vacuum Bag Assembly

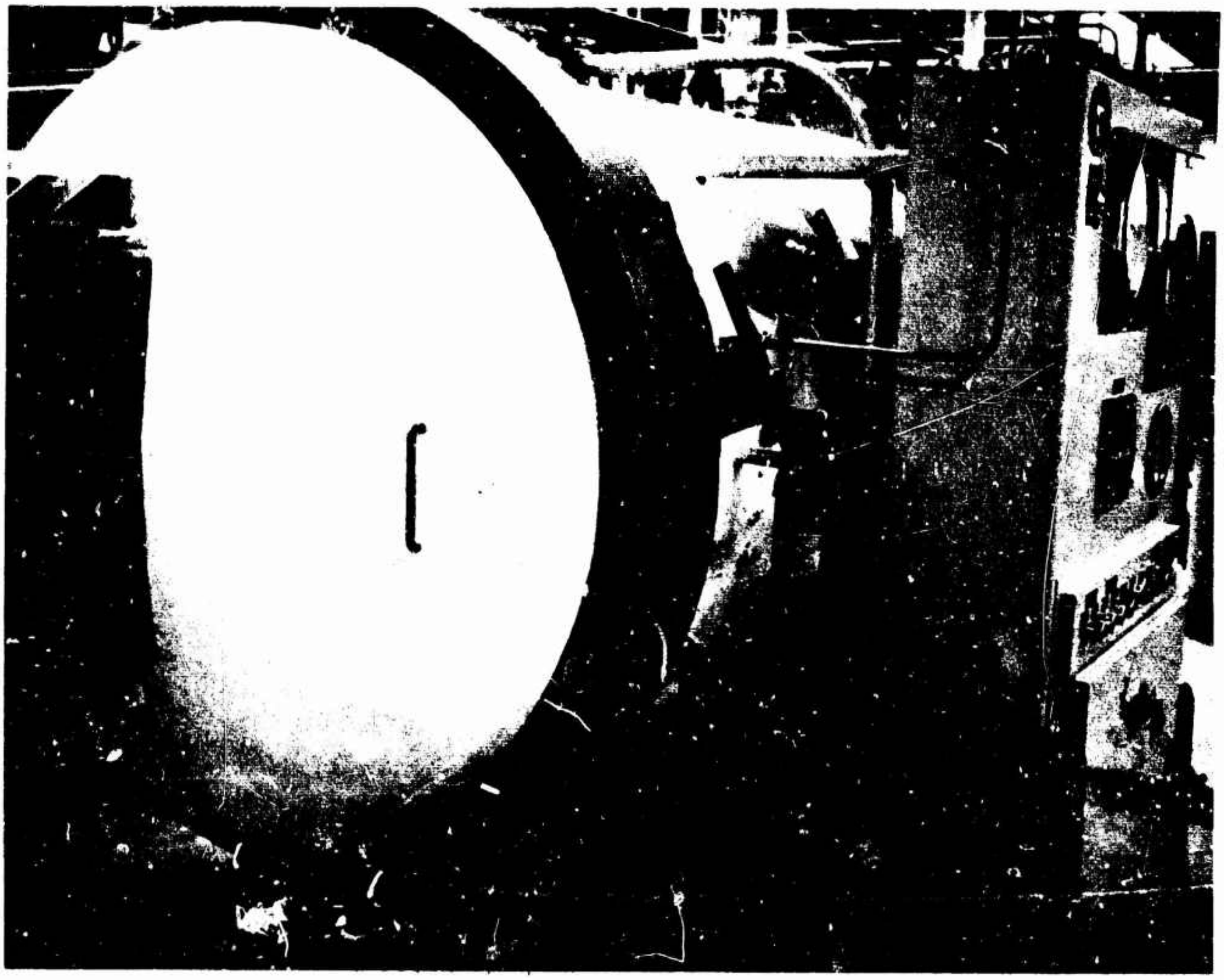

Figure 5. Resin Curing Autoclave